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Establishing the Biodynamics Data Resource (BDR): Human Volunteer Impact Acceleration Research Data in the BDR

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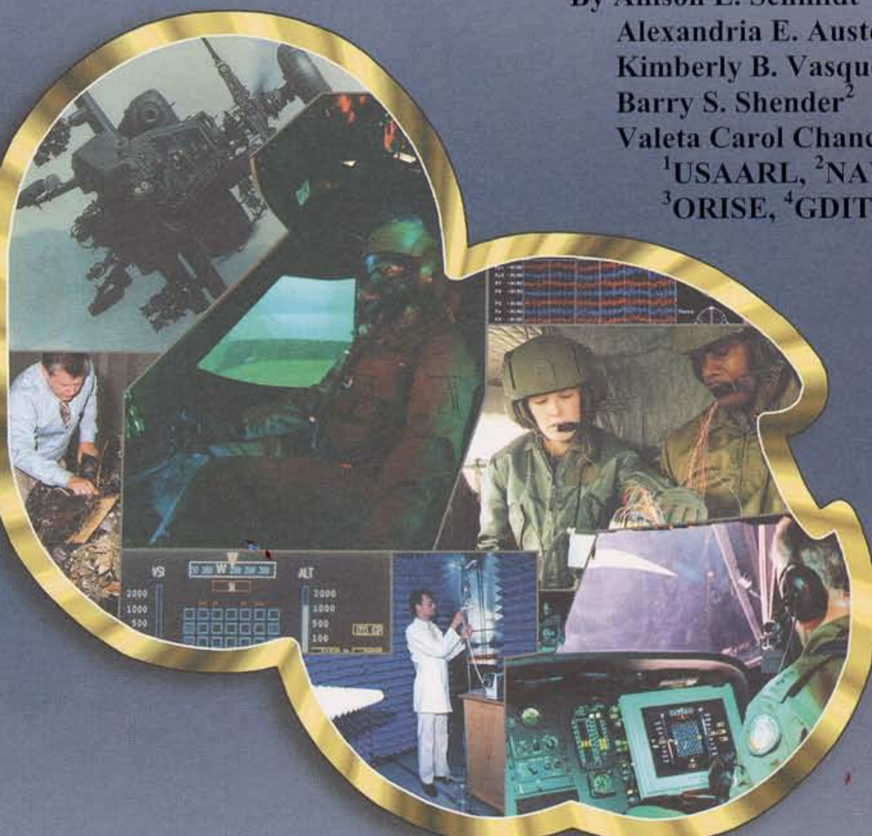

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14. ABSTRACT

One of the most noteworthy collections of impact exposure data was generated at the U.S. Naval Biodynamics Laboratory (NBDL). Over 25 years, NBDL conducted thousands of impact acceleration exposures with hundreds of human research volunteers. The resulting volumes of kinematic and physiological data serve as a foundation for injury biomechanics research, model validation, and biofidelity requirements. In 2007, the U.S. Army Aeromedical Research Laboratory (USAARL), in collaboration with the U.S. Naval Air Systems Command (NAVAIR) Human Systems Department, took possession of the collection, including physical and electronic data, films, and equipment. The Biodynamics Data Resource (BDR) was established to preserve and restore the inaccessible materials and open to researchers the wealth of experimental data. This paper reflects the initial stages of the project and provides an overview of the human impact acceleration work conducted at NBDL.

15. SUBJECT TERMS

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Summary

One of the broadest and most noteworthy collections of human impact exposure data was generated between 1971 and 1996 at the U.S. Naval Biodynamics Laboratory (NBDL) in New Orleans, Louisiana. Over the course of these 25 years, NBDL conducted several thousand impact acceleration exposures, supported by hundreds of human research volunteers. These subjects and carriages were thoroughly instrumented, with data collected from multiple accelerometer arrays, physiological recording devices, and high speed cameras. Responses were measured from 3,430 non-injurious human runs on NBDL's horizontal and vertical accelerators with frontal, lateral, oblique, and axial impact orientations. The volumes of data collected at NBDL serve as a foundation for neck injury mechanism research, model validation, and biofidelity requirements for various anthropomorphic test devices. After NBDL's closure in 1996, custody of the laboratory's materials underwent multiple transfers, and its extensive collections of human biodynamics became unavailable to the Department of Defense and the civilian injury biomechanics research communities. During this time, much of the material became disorganized, some of the materials deteriorated, and electronic document and database formats used at NBDL became obsolete and inaccessible.

In 2007, the U.S. Army Aeromedical Research Laboratory (USAARL), in collaboration with the U.S. Naval Air Systems Command (NAVAIR) Human Systems Department, took possession of the NBDL collection; among the acquired materials are documentation (e.g., protocols, consent forms, researcher notes, internal reports), kinematic data (e.g., high speed film and acceleration), physiological response data (e.g., electroencephalograms, electrocardiograms, and electromyograms), and biomedical data (e.g., X-rays and anthropometric measurements). USAARL and NAVAIR established the Biodynamics Data Resource (BDR) to restore, digitize, and preserve the materials and to construct a thoroughly searchable database that would open to researchers the wealth of invaluable experimental data, much of which is unpublished and cannot be reproduced. This paper reflects the beginning stages of the BDR reconstruction project and provides an overview of the human impact acceleration work conducted at NBDL.

Preface

This research was supported in part by an appointment to the Postgraduate Research Participation Program at the U.S. Army Aeromedical Research Laboratory (USAARL) administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and USAARL.

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Introduction

In 1971, the Naval Biodynamics Laboratory (NBDL) was established for the primary purpose of studying human response to impact acceleration. NBDL was located on the National Aeronautics and Space Administration's (NASA) Michoud Assembly Facility in New Orleans, Louisiana (Figure 1). The laboratory operated as a detachment of the Naval Aerospace Medical Research Laboratory (NAMRL) until 1980, when it was designated as an independent command. The scope of NBDL's mission gradually expanded to include research into human performance and response to ship motion and vibration.

NBDL researchers used several unique motion devices, including horizontal and vertical accelerators, when conducting research on the effects of mechanical forces on humans. Several thousand impact acceleration exposures, referred to as "runs," were completed and supported by hundreds of human research volunteers (HRVs). The HRVs were positioned and restrained in a carriage attached to either the horizontal or vertical accelerator. A controlled impact acceleration pulse was applied to the resting carriage to simulate various types of impact (e.g., frontal, lateral). The carriage and volunteer were instrumented with arrays of accelerometers and phototargets, and high speed cameras were mounted to the carriage to capture the kinematic reaction to impact. Physiological data, such as electromyograms, were often also collected.

Figure 1. The Michoud Assembly Facility with the enclosed horizontal accelerator track extending out of the building.

In addition to the horizontal and vertical accelerators, NBDL housed a ship motion simulator with a 22-foot stroke for human factors studies, a tri-axial motion desensitization chair, and a man-rated electrohydraulic vibration system.

The Navy's research programs continued for over two decades, until NBDL was closed by the Base Realignment and Closure (BRAC) committee in 1996 (Naval Biodynamics Laboratory, 1996). The materials and equipment remained in place, but laboratory operation was turned over to the University of New Orleans, and the laboratory's name was changed to the National Biodynamics Laboratory. The U.S. Navy retained ownership of the data collected by NBDL, and in 2005 the U.S. Naval Air Systems Command (NAVAIR) Human Systems Department began overseeing the data preservation. The National Biodynamics Laboratory was permanently closed in 2007 when NASA repurposed the space the lab was occupying.

In 2007, through collaboration with the NAVAIR Human Systems Department, the U.S. Army Aeromedical Research Laboratory (USAARL) took physical custody of the NBDL materials, including physical and electronic data, films, photographs, and equipment. Unfortunately, by this time much of the material had become disorganized, some material had deteriorated, and electronic document and database formats that were used at NBDL had become obsolete and inaccessible. USAARL and NAVAIR established the Biodynamics Data Resource (BDR) at USAARL to restore, preserve, and organize these materials and construct a functioning, accessible database. Such a database will open to researchers a wealth of invaluable experimental data, much of which is unpublished and cannot be reproduced. This paper reflects the beginning stages of the BDR reconstruction project, during which time the materials were organized, assessed, and cataloged to account for the contents of the collection.

Methods

The primary goal of BDR is to establish a comprehensive, cross-referenced digital database of the NBDL impact acceleration data and its supporting documentation. To achieve this objective, it was first necessary to organize the physical materials and quantify the volume of data produced at NBDL. However, organizing and cataloging the BDR collection has proven to be a challenging task. The 25 years of research conducted at NBDL resulted in a massive volume of experimental data, results, and publications; USAARL received over 40 tons of these materials, not including laboratory equipment. Following the closure of NBDL, the materials were moved piecemeal to several different locations and were subjected to various organizational schemas. While individual pieces of information retained identifiers – dates, subject numbers, and run identification numbers – the original organization and indices maintained by NBDL were mostly lost. The data arrived at USAARL in disorder.

The sheer volume of the data from NBDL made it difficult to understand the types and amounts of materials in the collection without an organizational structure. Therefore, conceptualizing and implementing a broad organizational strategy was a high priority. The overall organizational schema served multiple purposes. First, the organizational process provided BDR personnel with a deeper understanding of the materials in the collection and elucidated the relationships between the data sources. Additionally, the organization contributed to the design of the database structure and development of a process for digitizing the physical materials.

The overall organizational strategy began by categorizing materials into three broad categories – HRV-related, run-related, and project-related. Within the first two categories, data clusters were created and internally organized. In the HRV-related category, data clusters such as medical records and anthropometric X-rays were arranged by HRV number; such materials with identifiable data were secured in accordance to current privacy protection standards. In the run-related category, data clusters, such as high speed films, run summaries, and raw data charts, were organized by run number. Materials related either to laboratory operations or to many sets of experiments were placed in the project-related category and organized chronologically. Data clusters in this category included contracts, contract reports, intra-office and technical memoranda, NBDL publications, and reference materials.

Once an organizational schema was implemented, work began on describing the scope of BDR's content. The first cataloging effort focused on describing the published works of NBDL. Several partial bibliographies were included in NBDL command histories and library lists; these were condensed into a comprehensive ProCite® Version 5 database that contains over 500 records and includes an inventory of the manuscripts currently in BDR's possession. The publication database serves as a searchable source of reliable information about the body of work conducted at NBDL and is instrumental in identifying unpublished data.

While NBDL researchers assigned a run identifier to each test, no reliable, comprehensive index remained to describe the basic information about the tests that the run numbers represent (e.g., direction of applied acceleration pulse, acceleration intensity). Therefore, a run index table was constructed to provide a reliable listing of the parameters of each run and to quantify the content in the BDR collection. Each entry in the run index contains information such as the NBDL run number, subject identification number, the acceleration direction and G-level, and the purpose of the run. No single original source could be used to construct this index, however. As the runs were conducted, researchers and technicians produced several different documents that described the parameters of each run. Some of these included schedules of the runs to take place, camera set-up logs, and a run summary sheet generated immediately after a run. These summary sheets contained both manually-entered and instrumentation-generated data. Not only were these sources designed to hold different types of information, but none of them in isolation is reliable enough to be the basis for a reconstructed run record. Significant run commentary was often only recorded on a single source, and any one of these sources could contain an error or fail to reflect a test change. Therefore, multiple sources are needed to reconstruct a trustworthy, comprehensive entry for each run, and the run index is being continually refined as more sources of run information are found and verified. An excerpt of the run index is presented in appendix A.

Finally, there is a large set of materials whose significance is not readily assessed. Much of this set consists of the files maintained by individual NBDL researchers; those files contain notes, hand-written calculations, correspondence, and partial files. The greatest obstacle to labeling and categorizing this information is the lack of context surrounding it. Some of these materials came to BDR separated into boxes of researchers' work, and some arrived in boxes as it was collected from NBDL as it was being decommissioned. Attempting to physically integrate these materials into the rest of the collection would be futile; however, there is much valuable

information contained in these assorted papers. As the BDR database is developed, a digital copy of these materials will be produced and maintained. The structure of the database will enable these materials to be associated with relevant data.

Results

The ongoing organization and review of the materials described above has led to the creation of catalogues that describe, with acceptable veracity, the publications and impact data generated by NBDL. The evaluation of these catalogues and of other raw material has provided a better understanding of NBDL's capabilities and accomplishments.

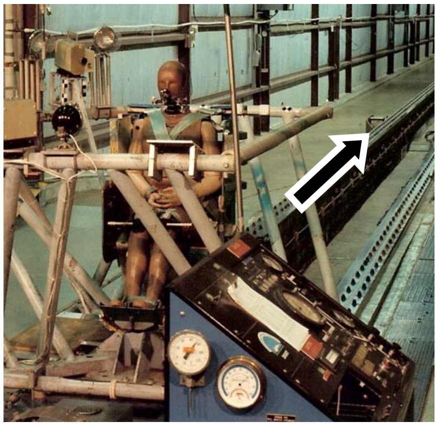
Impact motion device research

Horizontal accelerator

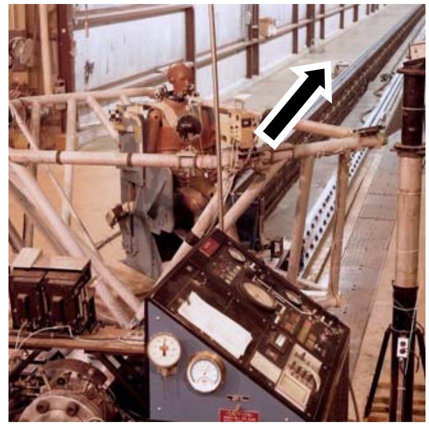
The majority of impact acceleration research at NBDL was conducted on a horizontal accelerator. Since 1972, researchers logged 6,600 total horizontal runs, including 3,614 human tests. The horizontal accelerator was powered by a 12-inch diameter, nitrogen-pressurized HYGE™ system, which propelled the sled carriage and its occupant with a thrust of up to 225,000 pounds of force. After the controlled acceleration pulse, the sled was gently decelerated by friction at a rate of 7 to 13 feet per second squared over the 700-foot enclosed track (Naval Biodynamics Laboratory, 1996). Anthropomorphic test devices (ATDs) were used to develop and verify the test equipment and perform daily safety checks.

Multiple sleds were used to orient volunteers in different directions relative to the thrust vector (Figure 2). Run directions were referred to by the direction of the thrust vector expressed in a subject-centered coordinate system. In this system, +X was to the subject's front, +Y was to the subject's left, and +Z was in the subject's superior direction. HRVs were fully restrained except for the head and neck and received non-injurious impact accelerations replicating frontal (-X), lateral (+Y), and oblique (-X+Y) impacts. Axial accelerations (+Z) were applied to HRVs in the supine position to mimic the acceleration of an ejection seat, while runs simulating aircraft crashes were conducted in the frontal impact direction with the seat pitched upward (-X+Z).

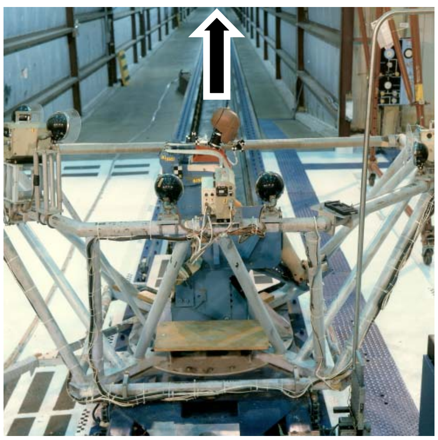
Of the 3,614 exclusively male human runs conducted on the horizontal accelerator, data were successfully recorded for 3,040 runs. Impact exposures on the horizontal accelerator are categorized by run direction in Table 1. Tests in the -X (frontal impact) direction were the most numerous and were conducted at the highest peak accelerations. The next most frequent test direction was the +Y (lateral impact) orientation, followed by the -X+Y (oblique impact) tests. The horizontal impact tests are broken down by acceleration level in Figure 3. Runs with instrumentation failures, aborted tests, and the 529 non-impact stationary runs are not captured in Table 1 or Figure 3. In the non-impact tests, HRVs would be restrained in the sled for voluntary motion range assessments or to take initial position films.



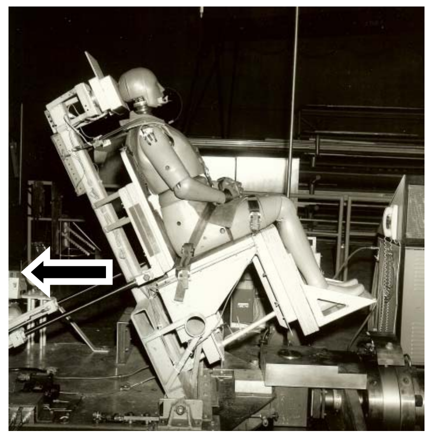
-X: The subject is positioned facing the accelerator, simulating frontal impact.



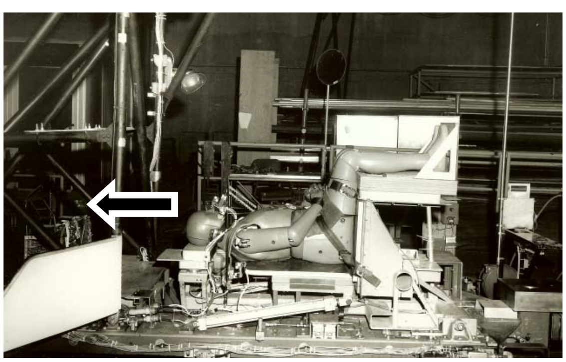
-X+Y: The subject is positioned at 45 degrees to the accelerator.

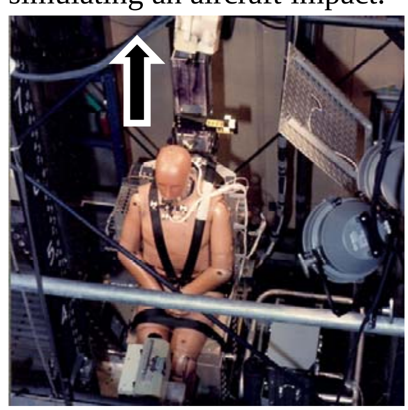


+Y: The subject is positioned perpendicular to the accelerator, simulating lateral impact.



-X+Z: The subject is positioned facing the accelerator and pitched up, simulating an aircraft impact.





+Z: Runs were completed on both the horizontal accelerator (left) and vertical accelerator (right). +Z axial accelerations simulate aircraft ejection and ship shock.

Figure 2. Demonstrations of test orientations by anthropometric test devices.

Table 1.
Human impact acceleration exposures with recorded data, by acceleration direction on the horizontal accelerator.

Horizontal Accelerator Impact Exposures					
Direction	Gender	Accelerations (G)	Runs	HRVs	Years
-X (Frontal)	M	2.0 - 15.9	1,065	92	1974 - 1986
+Y (Lateral)	M	1.8 - 11.3	915	52	1976 - 1982
-X+Y (Oblique)	M	2.0 - 13.1	545	41	1978 - 1982
+Z (Axial)	M	2.0 - 12.5	380	53	1986
-X+Z, 10 deg pitch	M	3.0 - 7.1	93	10	1986
-X+Z, 30 deg pitch	M	3.0 - 8.2	42	7	1982 - 1988
Summary:	M	1.8 - 15.9	3,040	164*	1974 - 1988

*Note: This total represents the number of unique HRVs participating in all runs; most HRVs were exposed to accelerations in more than one direction.

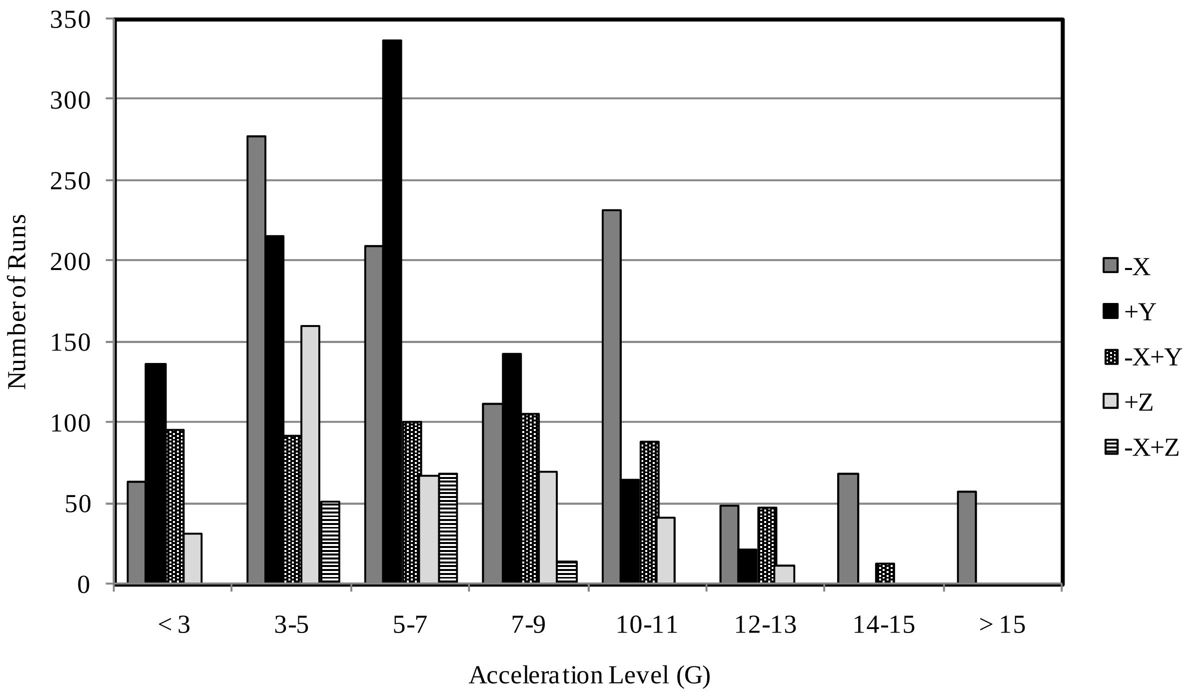


Figure 3. Distribution of impact acceleration levels for human runs conducted on the horizontal accelerator.

Vertical accelerator

In 1986, a vertical accelerator was added to NBDL's resources. This nitrogen-powered HYGE™ system supplied a +Z acceleration pulse, propelling the instrumented test carriage up a 42-foot vertical track with 40,000 pounds of thrust (Naval Biodynamics Laboratory, 1985). The vertical testing provided a more authentic ejection seat simulation than was achievable using axial accelerations on the horizontal accelerator. Additionally, the vertical accelerator was used with anthropomorphic test devices (ATDs) to simulate the underwater explosive forces experienced by personnel onboard ships.

A total of 1,184 runs were conducted on the vertical accelerator. Human testing began on the vertical tower when the equipment was man-rated in February 1990 (Naval Biodynamics Laboratory, 1990). Over the following five years, 593 human runs were completed; of these, data were collected from 390 impact acceleration runs, with the remainder of human runs composed of non-impact data collection events and runs that did not produce data. The experiments conducted on the vertical accelerator also included a set of 59 runs that constituted the only female impact acceleration data collected at NBDL. Details of the male and female vertical accelerator data sets are shown in Table 2, and the vertical impact tests are categorized by acceleration level in Figure 4.

Table 2.
Listing of human impact acceleration exposures with recorded data on the vertical accelerator. The impact acceleration work in 1993 to 1994 employed ATDs.

Vertical Accelerator Impact Exposures					
Direction	Gender	Accelerations (G)	Runs	HRVs	Years
+Z	M	2.2 - 12.4	331	44	1990 - 1992
+Z	F	2.6 - 9.2	59	9	1995
Summary:	M & F	2.2 - 12.4	390	53	1990 - 1995

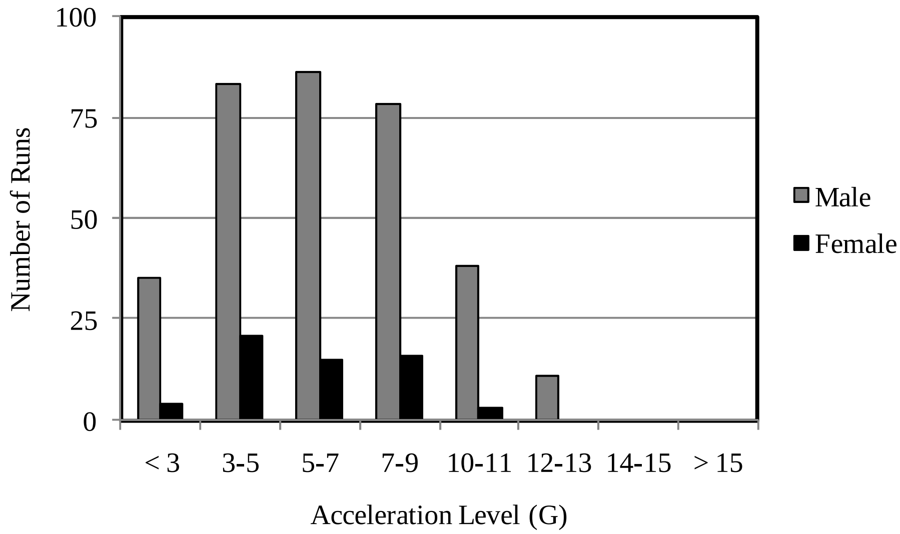


Figure 4. Distribution of impact acceleration levels for human runs conducted on the vertical accelerator.

Human research volunteers

A critical component of the research programs at NBDL was the recruitment and enrollment of human research volunteers (HRVs). The HRVs were junior enlisted Navy personnel who volunteered and passed a rigorous program of qualification examinations to ensure their physical and psychological fitness for participation. The entrance examinations comprised a battery of tests, including cardiologic, orthopedic, dental, and ophthalmologic exams, among others. Of the thousands of volunteer applicants that were interviewed, fewer than 300 HRVs qualified for NBDL research programs. Of the qualified HRVs, 211 individuals received impact acceleration exposures.

Each HRV gave written informed consent before participating in biodynamics experiments. The informed consent process for new HRVs was continually updated as requirements increased over the decades. Each volunteer began a test series with low intensity exposures. Following each impact event, the volunteer rested for a day. Then, if the HRV was willing and had not experienced pain, the acceleration level was either repeated for reliability or was increased by 1 to 2 Gs. Thus the volunteers stationed at NBDL received a wide range of exposures; many volunteers received only a single impact, while a few HRVs participated in multiple studies and made over 80 runs each. The frequency of repeated exposures is shown in Figure 5.

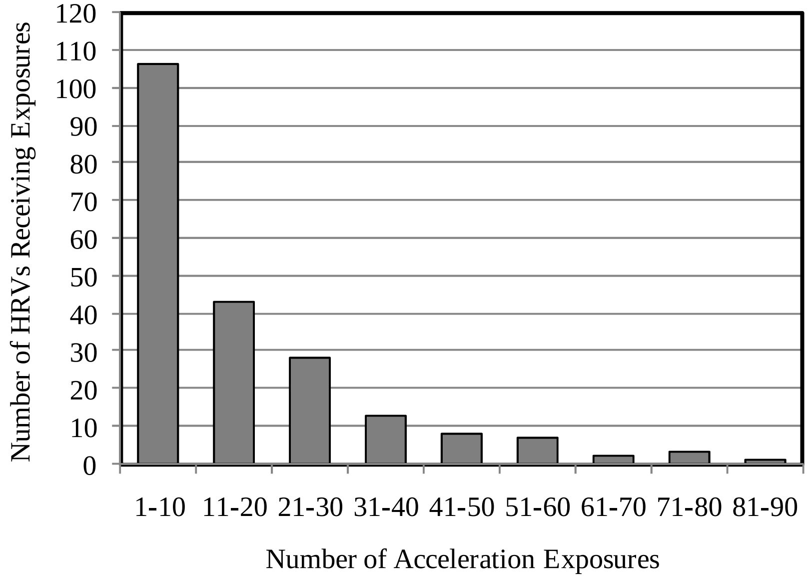


Figure 5. HRVs receiving different numbers of impact exposures.

Volunteers typically remained at NBDL for an 18-month tour of duty, performing other duties at the command when not actively engaged in research programs. Tours concluded with a comprehensive discharge examination. Follow-up examinations were also conducted for volunteers exposed to numerous or high intensity accelerations to monitor and study the long-term health, performance, and physiological effects of participation in biodynamics experiments (Naval Biodynamics Laboratory, 1982).

Extensive medical records were kept for all of the qualified volunteers. During qualification exams, clinical X-rays (Figure 6) of the cervical, thoracic, and lumbar spine were collected to screen for orthopedic contraindications. Another set of stereo X-rays were taken to measure anatomical landmarks and define the anatomical coordinate system (Francis, 1995). In these radiographs (Figure 7), radiopaque markers were placed at external anatomical markers and in instrumentation mounts to relate the anatomical and instrumentation data (Francis, 1991). An extensive set of anthropometric measurements were also taken for each volunteer. An example of the measurements taken is presented in appendix B.

Figure 6. A cervical spine X-ray taken during a volunteer's medical qualification process.

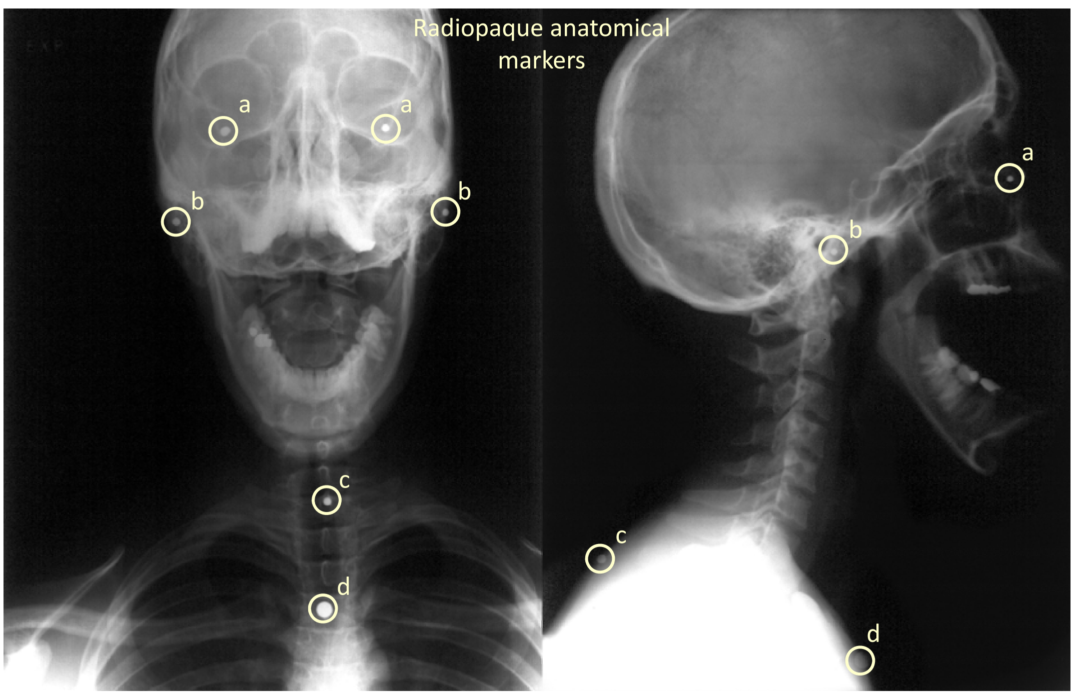


Figure 7. Anterior-posterior and lateral anthropometry X-rays were taken simultaneously. Lead markers, which appear as white dots, are attached to the (a) infraorbital notches, (b) auditory meatus, (c) instrumentation mount, and (d) suprasternal notch (Francis, 1991).
*Note: Figure brightness has been adjusted for print.

Figure 8. Three (non-consecutive) frames from one of the high speed films, with phototargets on the mouth mount, T1 mount, and carriage. Approximately 100 frames were recorded during the impact event.

Data collected

One of the primary objectives of the impact acceleration program was to characterize the human kinematic response to impact. An instrumentation system was designed to capture the motion of key anatomical segments through the redundant measures of film and accelerometer recordings. For the film analysis, a set of up to 14 phototargets was affixed to a rigid plate at each anatomical site of interest. Three to five carriage-mounted, high speed cameras recorded the event at 500 to 1,000 frames per second (Figure 8), and the phototargets in the film were tracked to yield a direct measure of displacement over time (Willems et al., 1981; Prell and Anderson, 1993; Kilgore and Gottbrath, 1984).

An array of 6 or 9 accelerometers were mounted on the same plates as the phototargets to concurrently capture angular and translational accelerations. The acceleration data were appropriately transformed and integrated to derive displacement. The trajectories calculated from the accelerometers and from the phototargets were compared, and the correlation between the two was used to confirm the reliability and quality of the data (Willems et al., 1981). A test setup with typical kinematic data instrumentation is shown in Figure 9.

In addition to kinematic data, measures were also taken to characterize the human physiological response to impact acceleration. Among these were somatosensory evoked potentials (SEPs), electroencephalograms (EEGs), electrocardiograms (ECGs), and electromyograms (EMGs) (Naval Biodynamics Laboratory, 1996, 1990). Additionally, respiratory and heart rate monitors were sometimes used during the event to provide an additional means of safety monitoring (Lotz, 1990).

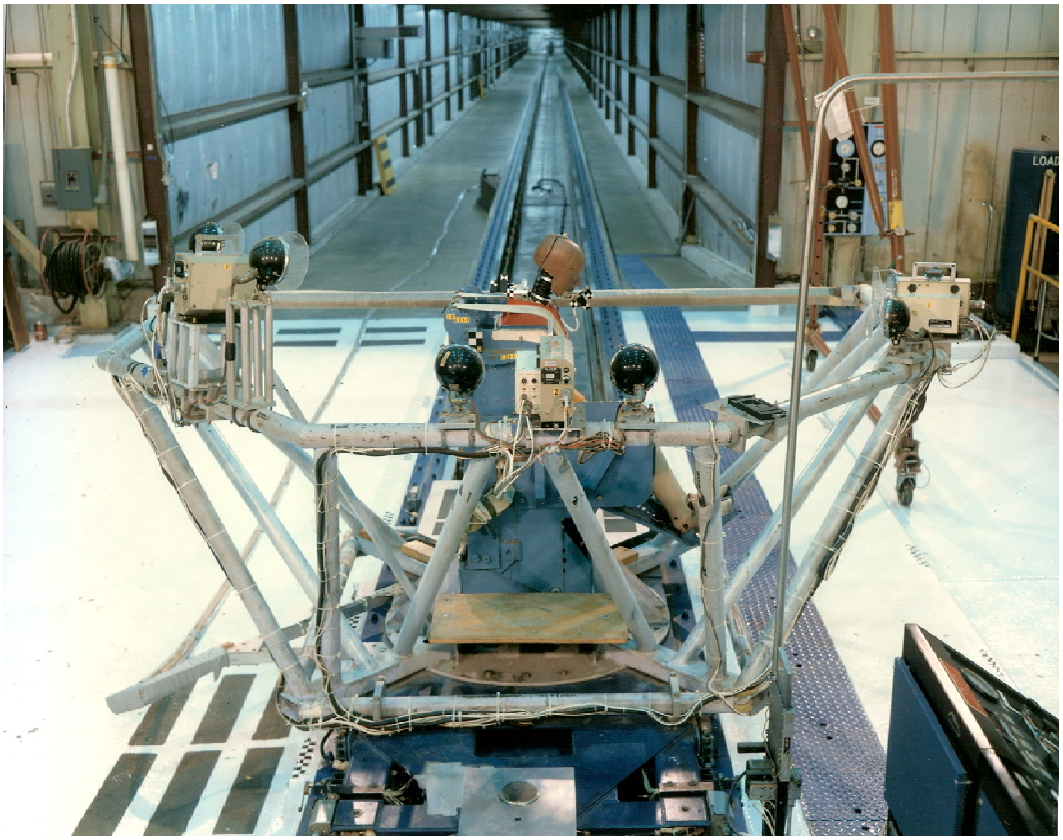


Figure 9. ATD positioned for +Y impact acceleration on the horizontal accelerator. Three high speed cameras and an array of high-intensity lamps are rigidly mounted on the carriage to capture motion throughout the impact event. Phototarget/accelerometer clusters are affixed to the ATD's mouth and base of neck.

Special test series

In addition to the regular impact runs, some NBDL studies were conducted using special procedures. One such study focused on the effects of added head mass during an impact acceleration. In these tests, volunteers would wear a customized fiberglass helmet, shown in Figure 10. A rack was affixed to the top of the helmet which allowed researchers to vary combinations of helmet weight and center of gravity. These added weights ranged from 275 to 600 grams and were placed at multiple locations: at eye level, on top of the head, offset 45 degrees in pitch, or offset with one weight at 45 degrees and another at 135 degrees. Helmeted runs with and without added weight were conducted both in the -X direction on the horizontal accelerator and in the +Z direction on the vertical accelerator. The added head mass runs were performed at slightly lower maximum acceleration levels than unhelmeted tests, and extra attention was given to capturing the initial positions of the volunteer and helmet. The added head mass exposures are shown in Table 3; these runs were also included in the horizontal and vertical accelerator overviews in Table 1 and Table 2 above.

Figure 10: The added head mass apparatus used in the vertical accelerator experiments. The addition of weights replicates the masses of the helmet-mounted devices that aviators would likely be wearing in a dynamic event. Each volunteer's fiberglass helmet was custom fit to minimize relative movement.

Table 3.
Runs conducted under added head mass studies. For the runs in the +Z direction, unhelmeted runs were included, and HRVs were assigned more than one head mass condition.

Added Head Mass Series						
Direction	Head Mass Condition	Gender	Accelerations (G)	Runs	HRVs	Years
-X	Helmet No Weight	M	3.0 - 9.14	37	6	1985 - 1986
	Helmet With Weight	M	3.0 - 8.02	28	5	1985 - 1986
+Z	Unhelmeted	M	3.1 - 10.2	18	12	1991
	Helmet No Weight	M	2.8 - 9.0	14	9	1991
	Helmet With Weight	M	2.8 - 9.2	113	16	1991

Another variation on impact acceleration experiments involved changing the initial head and neck positions of the volunteers. In these runs, a volunteer would be instructed to maintain a non-neutral position prior to the time of impact. Most positions were described as combinations of neck up or neck forward and chin up or chin down. The volunteers were also sometimes instructed to turn or tilt their heads to one side.

In addition to impact runs, a set of non-impact, stationary runs were conducted to study voluntary motion ranges of the head and neck. In these "head nod" experiments, volunteers were restrained in the carriage and instrumented as though preparing for an impact acceleration. The head motion was performed in yaw, pitch, and roll directions at two speeds. The slower motion was intended to determine the volunteers' maximum angular displacements. A volunteer moved through his full range of head and neck motion over 3 seconds, and motion was tracked and analyzed with high speed film. The faster motion was intended to determine the HRV's maximum voluntary angular velocity. The movement was completed in approximately 1 second, and in addition to high speed film, the inertial data acquisition system also recorded the motion. In total, 489 voluntary motion runs were conducted with male volunteers on both the horizontal and vertical accelerators.

Discussion

The body of work conducted at NBDL and contained in BDR represents some of the most noteworthy human impact acceleration experiments in injury biomechanics. The results of these tests have been used to investigate injury mechanisms, to compare the kinematic responses of volunteers to post-mortem human subjects, and to define biofidelity requirements for ATDs and computational models (Thunnissen et al., 1995). Still, much valuable data remains under-utilized and unpublished.

BDR contains data collected from almost 7,800 runs performed during more than 25 years of research. More than half of these runs investigated human volunteer response to impact. In addition to this kinematic response data, BDR contains a wealth of pre- and post-event biomedical evaluations. Although some studies were performed to answer specific applied research questions, the majority of the head and neck response data were recorded during generic pre-defined impacts of increasing magnitude in a specific direction using one of two unique motion devices. These man-rated motion devices – the horizontal accelerator sled and vertical accelerator tower – were specifically designed to perform human impact acceleration research and represent only a portion of the facilities and resources that created an unrivaled research environment at NBDL. The collections within BDR not only document the rich research performed at NBDL, but also the facilities, resources, policies, and the pioneering methodology developed during NBDL's operations.

Simply collecting the data and documents produced by NBDL's immense research programs will not satisfy the requirements of future research, however. Researchers' needs demand a well-planned database structure with thorough links between related items, such as kinematic data, instrumentation setup, and related methodology. Current investigators do not have the

inherent familiarity of those who originally designed and conducted the experiments, so more information must be provided to make the data useable. Therefore, the database structure must provide two functions. First, users must be able to browse and filter the database using a number of different parameters. This function will allow users to see what information is available and to identify data sets of interest. Second, the relationships built into the database must provide the original context of the test. For instance, when a set of kinematic data is selected, the protocols and documentation covering those runs should be offered. Furthermore, the system should identify other materials that the database user might not know exist, such as a memorandum describing a particular instrumentation anomaly that affected the selected data.

The materials used to populate this database will come both from scanned physical materials and from previously produced electronic materials. In choosing sources for inclusion in the database, authenticity and quality are the highest priorities. In the case of primarily physical materials – such as medical records, high speed film, and photographs – the original documents are easy to identify, and high-quality scans can be made. Identifying primarily electronic materials for inclusion in the database is significantly more complicated.

These primarily electronic materials consist mostly of accelerometer and physiological data. The difficulties in dealing with these materials stem from a trade-off between accessibility and veracity. These data were originally collected and stored on magnetic tapes. Subsequently, they were filtered, analyzed, and conditioned in various ways, updated to conform to newer systems, and stored on a variety of storage media. While the newer material is likely in better physical condition and is easier to access, the challenge lies in identifying what operations have been performed on the data. Alternatively, older versions of materials, whose pasts may be easier to trace, could be used as the primary data source. However, the older media have not been properly stored and maintained, and the magnetic tapes may have undergone degradation so severe that their contents are no longer viable. Furthermore, obtaining the hardware and the software necessary to access some of the various obsolete types of storage would be challenging. Even much of the easily accessible media, such as 3.5-inch floppy disks, was created with software so old or specialized that viewing the contents is not trivial. Despite these challenges, the rich biodynamics data in BDR can provide us an extensive look at human response to directional impact accelerations.

Conclusion

The data contained in BDR represents approximately 3,430 instrumented human impact acceleration experiments, and the body of work continues to be vital to further understanding how the human body reacts to impacts. The current environment concerning the protection of human subjects renders these experiments unrepeatable, intensifying the need to make this data accessible to the Department of Defense and to the scientific community at large. Toward this goal, the materials have been broadly organized and catalogued, and efforts to digitize and preserve the BDR collection are underway. The end result will be a thorough, searchable database that will allow researchers to access the data and advance the field of injury biomechanics.

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Appendix A.

Run index.

Table A-1 provides a listing of the runs conducted over the course of one day and an excerpt of the descriptive parameters for each run. The run number prefix denotes the direction of the track, not of the exposure, where LX runs were on the horizontal accelerator and LZ runs were on the vertical accelerator. Every record was checked against original documents; however, this data should not be interpreted as absolute, as the run index is undergoing continual review and refinement.

Table A-1.
Truncated sample entries from run index, compiled 30 April 2009.

Run Number	LZ0964	LZ0965	LZ0966	LZ0967
Subject ID Number	D00006	H00253	H00254	H00269
Gender		M	M	M
Run Description	Dummy test	Human test EMG, EOG	Human test EMG, EOG	Human test EMG, EOG
Date	10/20/1992	10/20/1992	10/20/1992	10/20/1992
Direction	+ Z	+ Z	+ Z	+ Z
Attempted Peak (m/s/s)	50	50	50	50
Time at Trigger	07:58:55.6265	08:51:40.9191	09:42:09.6089	10:28:42.1283
Elapsed Time at First Motion (msec)	222.7	224.9	221.9	221.4
Elapsed Time at Accel End (msec)	373.5	368.5	371	372.5
Duration at/above 75% peak accel (msec)	53.5	69	62.5	60.5
Rate of Carriage Accel Onset (m/s/s/s)	739.3	814.1	696.9	696
Peak Carriage Accel (m/s/s)	49.41	49.96	48.081	48.45
Peak Carriage Velocity (m/s)	4.58	4.52	4.51	4.64
Carriage Displacement at Peak Velocity (m)	0.4	0.3	0.3	0.3
Set Pressure (psi)	200	200	200	200
Load Pressure (psi)	625	615	610	615
Trigger Pressure (psi)	450	450	450	450
Set Cylinder Length (m)	1.22	1.22	1.22	1.22
Load Cylinder Length (m)	1.07	1.07	1.07	1.07
Carriage Mass (kg)	509	494	491	492
Metering Pin	PIN006	PIN006	PIN006	PIN006
A/D sampling interval (s)	0.0005	0.0005	0.0005	0.0005
Distance Traveled (m)	1.17	1.12	1.07	1.09
Instrument 1	CARRIAGE	CARRIAGE	CARRIAGE	CARRIAGE
Amount ID 1	1	1	1	1
Imount ID 1	5196	5196	5196	5196

Appendix B.

Anthropometric measurements.

Throughout NBDL's history, detailed anthropometric measurements were taken of in-processing volunteers. In general, between 70 and 100 body measurements were taken for each subject. Table B-1 provides a sample of the data collected from a volunteer in the 1990s. The definitions of many of these measurements can be found in anthropometry handbooks and surveys, such as the tri-service Anthropometry and Mass Distribution for Human Analogues. Volume 1: Military Male Aviators (Armstrong Aerospace Medical Research Laboratory et al., 1988).

Table B-1.
A sample of anthropometric measurements collected.

Weight	Body Weight		
Height (Ht)	Stature	Nuchale Ht	Cervicale Ht
	T-1 Ht	Eye Ht	Traigon Ht
	Acromion Ht	Chin/Neck Ht	Axilla Ht
	Suprasternale Ht	Substernale Ht	10th Rib Ht
	Waist Ht (Omph)	Iliocristale Ht	ASIS Ht
	Trochanterion Ht	Gluteal Furrow Ht	Tibiale Ht
	Sphyrion Ht	Lateral Malleolus Ht	
Circumference (Circ)	Head Circ	Neck Circ	Scye Circ
	Chest Circ	10th Rib Circ	Waist Circ (Omph)
	Buttock Circ	Upper Thigh Circ	Mid-Thigh Circ
	Knee Circ	Calf Circ (Rt, Lt)	Ankle Circ (Rt)
	Axillary Arm Circ	Biceps Flexed (Rt, Lt)	Biceps Relaxed (Rt)
	Elbow Circ	Forearm Circ, Ext	Mid-Forearm (Rt)
	Wrist Circ	Hand at Meta III	
Breadths	Neck Breadth	Shoulder Breadth	Chest Breadth
	10th Rib Breadth	Waist Breadth	Bicristale Breadth (Bone)
	Hip Breadth (max)	Forearm-Forearm Breadth	
Depths	Chest Depth	10th Rib Depth	Waist Depth
	Hip Depth	Calf Depth	
Lengths (Lth)	Foot Lth	Foot Breadth	Acromion-Radiale Lth
	Ball of Humerus-Radiale Lth	Radiale-Stylion Lth	Shoulder-Elbow Lth
	Elbow-Grip Lth	Forearm-Hand Lth	Meta III – Dactylion Lth
	Hand Lth	Hand Breadth, Meta	Hand Depth
	Wrist Breadth (Bone)		
Sitting Dimensions	Sitting Ht	Eye Ht, Sitting	Tragion Ht, Sitting
	Cervicale Ht, Sitting	Shoulder Ht, Sitting	Knee Ht, Sitting
	Popliteal Ht, Sitting	Thigh Clearance	Buttock-Knee Lth
	Buttock-Popliteal Lth	Hip Breadth, Sitting	Biacromial Breadth
	Elbow Breadth, Rt and Lt (Bone)	Femur Breadth, Rt and Lt (Bone)	
Head Dimensions	Head Lth	Head Breadth	Bitragion Breadth
	Infraorbitale-Tragion	T-1 to Top of Head	T-1 to Nuchale
	T-1 to Mastoid (Vertical)	T-1 to Rt Tragion (Horizontal)	Top of Head to Prosthion
	Top of Head to Tragion	Top of Head to Menton	Wall to Tragion
	Wall to Prosthion	A-P Depth at Thelion	
Other Dimensions	ASIS (Rt) to Symphesion	ASIS (Lt) to Symphesion	Bispinous Breadth

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